

SYNTHESIS AND STRENGTH OF $\text{MgSO}_4 \cdot 11\text{H}_2\text{O}$ (MERIDIANIITE): PRELIMINARY RESULTS FROM UNIAXIAL AND TRIAXIAL DEFORMATION TESTS. P.M. Grindrod¹, A.D. Fortes¹, I.G. Wood¹, P.R. Sammonds¹, D.P. Dobson¹, C.A. Middleton¹, and L. Vočadlo¹, ¹Centre for Planetary Sciences, Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT UK. (p.grindrod@ucl.ac.uk).

Introduction: Hydrated magnesium sulfate minerals, such as kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$), hexahydrate ($\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$), epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), and meridianiite ($\text{MgSO}_4 \cdot 11\text{H}_2\text{O}$) are likely to be important planetary materials. On the icy moons, these hydrated phases have been suggested as possible non-water phases at the surface [e.g. 1,2,3], and may affect the possibility and rate of solid-state convection within the interiors. On Mars, meridianiite, hereafter called MS11, may be the most abundant hydrate mineral on the planet, and is important in studies of the present martian water budget [4]. The aim of this study is to expand the limited knowledge of the strength of hydrated magnesium sulfates, and MS11 in particular.

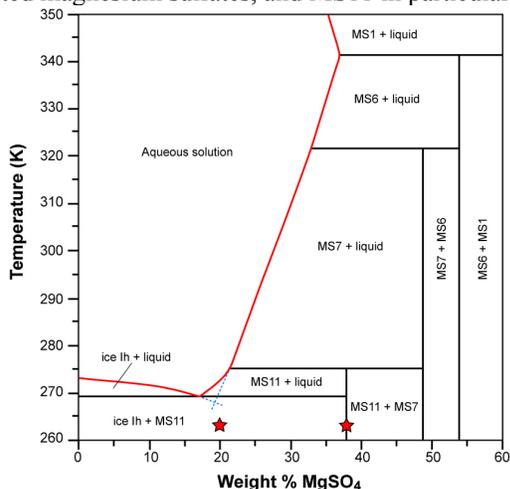


Figure 1. Binary phase diagram of the $\text{MgSO}_4\text{-H}_2\text{O}$ system (after [5,6]). Red stars show the composition and temperature of the deformation tests in this study.

Sample Preparation: We prepared MS11 samples for use in deformation tests using two different methods, to identify any influence of composition (Figure 1) on the strength of the sample.

1. *Quenching.* A stoichiometric solution (37.78 wt. % MgSO_4) was made up at $\sim 100^\circ\text{C}$, and placed in thin Perspex tubes of 25 and 40 mm in diameter. These tubes were then sealed as quickly as possible and placed in liquid nitrogen for ~ 24 hours. The goal of this method was to avoid known metastable phases near the eutectic composition [e.g. 5].

2. *Slow-freezing.* A solution of 20 wt. % MgSO_4 was made up at $\sim 60^\circ\text{C}$ and placed in a 40 mm diameter Perspex tube. The sample was then left at 0°C for 48

hours, to crystallize as much MS11 as possible, and then at -15°C for 24 hours, to allow complete crystallization. The aim of this method was to create a mixture of MS11 and water ice that is enriched in MgSO_4 .

For both types of sample we checked the presence of MS11 by placing a small volume of the sample onto a glass slide under an optical microscope in the cold rooms. We then heated the sample through the dehydration phase change to MS7 at $\sim 2^\circ\text{C}$, and observed a change in crystal habit and the release of water (Figure 2), described by [6]. We are currently in the process of determining the composition of each sample by using a cryo-stage with XRD analysis. No attempt has been made to control the grain size of the samples in this study. However, preliminary SEM analysis of the surface of a used indium jacket suggests that mean grain size through quenching might be very fine, perhaps $< 5 \mu\text{m}$. We are in the process of installing a cryo-stage on the SEM to analyse the samples themselves.

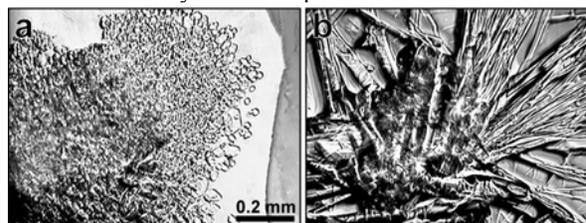


Figure 2. Observing the phase change from (a) MS11 to (b) MS7 while warming through 2°C . Same FOV for both images, which were taken ~ 170 s apart.

Triaxial Deformation Cell: We use a standard triaxial deformation cell housed in a cold room to perform deformation tests. We use nitrogen gas to create a confining pressure around the sample, which is placed in a sealed indium jacket to exclude the gas. For these tests we use a 10 kN load cell to provide a constant displacement rate, enforcing a constant strain rate (measured by an external LVDT), and a resultant force on the sample (measured internally by the load cell).

Before loading, all samples were lathed to the correct diameter (expansion during quenching led to a slight increase in the Perspex tube diameters) and the ends made parallel. All handling was conducted in cold rooms at -15°C , with no direct skin contact, to avoid unwanted phase changes. The samples were placed on the end cap of the inverted upper ram, covered with an indium jacket of the correct diameter, and

sealed by PTFE rings outside the jacket. The lower ram was placed on top of the samples and kept in place by a yoke, with minimal compression. The assembled ram and sample were then inverted and lowered into the pressure vessel using a hoist, before inserting the ram sleeve and breech nut (Figure 3). For tests with a confining pressure, the gas pressure was increased to the desired level and allowed to stabilize for approximately 30 minutes, whilst recording the strain with the external LVDT.

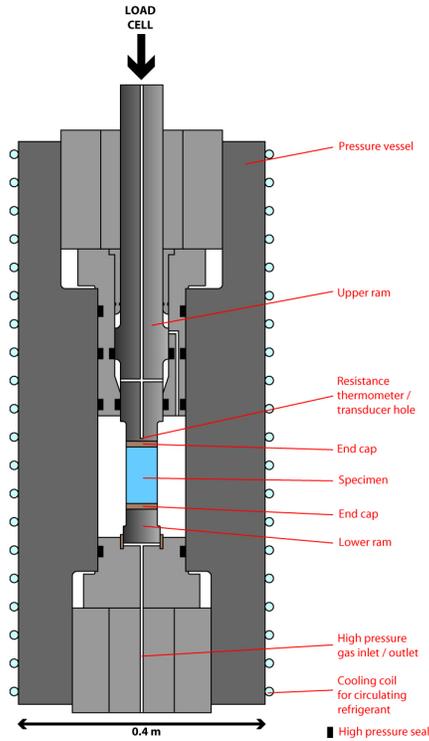


Figure 3. Sketch of the triaxial deformation cell, including sample location and high-pressure lines.

Results and Discussion: We conducted deformation tests at confining pressures of $P = 50$ MPa and $P = 0.1$ MPa, on samples of 25 and 40 mm diameter respectively. Where possible, we performed step-tests on a single sample by increasing the displacement rate. During these preliminary tests we have improved our methods to achieve strain rates of $\sim 10^{-9} \text{ s}^{-1}$.

From these preliminary data (Figure 4, Table 1), our samples of MS11 appear to be of similar, if not lower, strength to pure water ice under similar conditions. There are several possible reasons for these results, mostly related to sample preparation methods: (1) quenching produces a pore-rich sample; (2) quenching prohibits crystal intergrowth; (3) samples are very fine-grained, thus weak; (4) quenching produces micro-fractures; (5) we have not produced MS11; (5) MS11 really is weak at 263 K.

We can rule out reason 5 with some confidence, but if the sample does contain a large water ice fraction, then it is possible that the rheology is dominated by this phase. It is also possible that a combination of reasons 1-4 is responsible for the relative weakness of our samples. If MS11 has a similar rheology to ice I, then its presence may increase the likelihood of convection in icy moons or be a possible source for gullies on Mars. Therefore we are continuing deformation tests under both similar and different conditions, in order to test the above hypotheses.

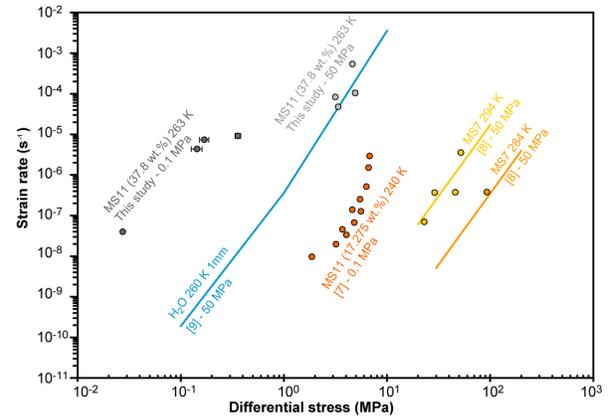


Figure 4. Preliminary results of our strength tests on MS11 (only 37.78 wt. % plotted) compared to those of previous studies [7] and other materials [8,9].

Table 1. Preliminary run data

Run	Sample (wt. %)	P (MPa)	T (K)	$\dot{\epsilon}$ (s^{-1})	σ (MPa)
3	37.78	50	263	1.04×10^{-4}	5.07
4	37.78	50	263	8.28×10^{-5}	3.25
5 (1)	37.78	50	263	4.75×10^{-5}	3.46
5 (2)	37.78	50	263	5.35×10^{-4}	4.78
6 (1)	37.78	0	263	3.96×10^{-8}	0.03
6 (2)	37.78	0	263	4.33×10^{-6}	0.15
6 (3)	37.78	0	263	7.31×10^{-6}	0.17
6 (4)	37.78	0	263	9.13×10^{-6}	0.37
8	20.0	0	263	3.56×10^{-9}	0.03

References: [1] Kargel J.S. et al. (1991) *Icarus*, 94, 368-390. [2] McCord T.B. et al. (1998) *Science*, 280, 1242-1244. [3] Dalton J.B. et al. (2005) *Icarus*, 177, 472-490. [4] Chou I.-M. and Seal R.S. (2007) *JGR*, 112, E11004. [5] Hogenboom D.L. et al. (1995) *Icarus*, 115, 258-277. [6] Peterson R.C. and Wang R. (2006) *Geology*, 34, 967-960. [7] McCarthy C. et al. (2007) *LPSC*, 38, #2429. [8] Durham W.B. et al. (2005) *JGR*, 110, E12010. [9] Goldsby D.L. and Kohlstedt D.L. (2001) *JGR*, 106, 11,017-11,030.